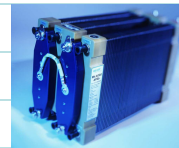




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# Outline

1

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- Introduction to Ballard
- Commercialization Timelines
- Why Fuel Cells
- Technology “Roadmap”
- Testing Capability
- Fleet Experience
- Automotive Path to Commercialization
- Manufacturing Capability
- Summary

[illegible]

- 
- A blue, rectangular laser unit, identified as the RAL-1000, is shown. It features a control panel on the front with several knobs and a small display screen. The unit is positioned on a light blue surface.

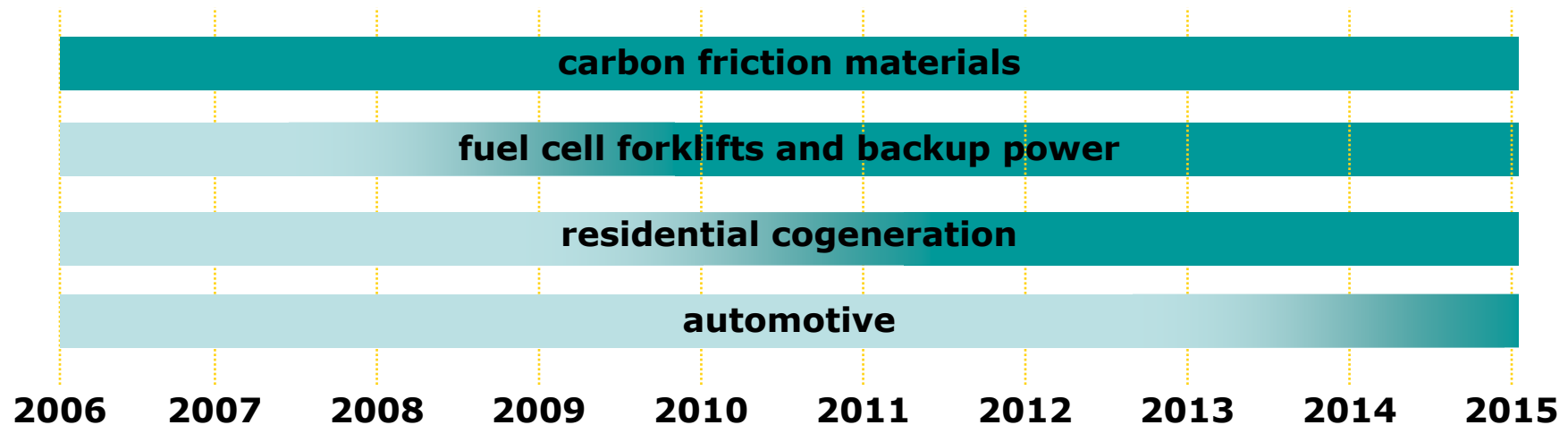


# Focused on Near and Long-Term Commercial Markets

3

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Ballard's products and services include: fuel cells & components, field service & parts and engineering services



*market commercialization timeline based on Ballard projections*

pre-commercial, positive gross margin sales

commercial sales

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# Fuel Cells – the Best Long-Term Solution

A series of colored squares (blue, green, yellow, orange, red) followed by a progress bar with 15 segments, where the first segment is filled with a blue gradient.



- *Fuel cells the most comprehensive solution to energy & environmental challenges: air quality, greenhouse gases and energy security*
- *Fuel cells and batteries complementary, not competing technologies.*
- *Unlike ICE hybrids, fuel cell hybrids enable **pure electric** drive trains.*
- *Hybridization accelerates commercial introduction of fuel cell vehicles.*



## 5

5

- 
- COST**
- Y-axis: USD \$ / kW NET (0 to 160)
- X-axis: YEAR (2002 to 2010)
- Legend:
- Ballard's achievement to date
  - 2020 and Ballard Target (USD \$/kW net)
- Notes:
- Ballard's achievement to date: 500,000 units per year
  - Estimated cost for automotive stack: 5-year design, including facilities and engineering
  - Platform price > \$300/kW
  - 2000: Stack area power: 100 kW, System net power < \$5/kW
- DURABILITY**
- Y-axis: STACK LIFETIME (Hours) (0 to 6000)
- X-axis: YEAR (2002 to 2010)
- Legend:
- Ballard's achievement to date
  - 2020 and Ballard Target (2,000 hours equivalent to 150,000 miles or 240,000 kilometers)
- FREEZE START**
- Y-axis: START-UP TIME TO 50% POWER (SEC) (0 to 210)
- X-axis: YEAR (2002 to 2010)
- Legend:
- Ballard's achievement to date
  - 2020 and Ballard Target
  - 2020 Ballard's revised 2020 Target
- Notes:
- 2000: 24 hours start-up time from 25°C to zero demonstrated at 2.5 MW power
  - No change in power from the negative cycle due to limited in the graph
- POWER DENSITY**
- Y-axis: WATTS NET / LITER (500 to 3000)
- X-axis: YEAR (2002 to 2010)
- Legend:
- Ballard's achievement to date
  - Ballard Target: 2,500 Watts/liter
  - 2020 Ballard Target: 2,500 Watts/liter
- Notes:
- System net power / Stack module volume
  - 2000: 2.5 MW power, 2.5 MW power
  - System net power < \$5/kW



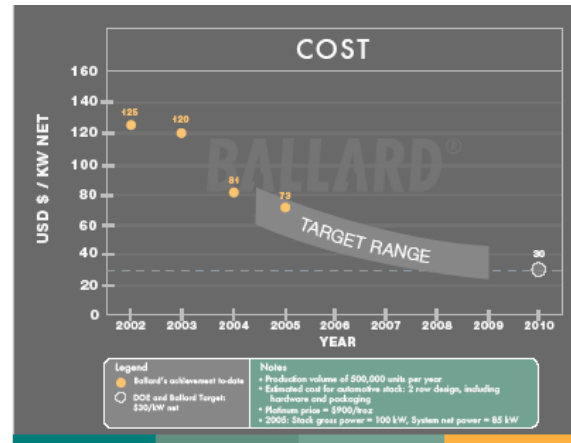
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# Technology Planning supporting "Road Map"

6

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External  
communication tool –  
**technology** progress



## Component Routemap

Technology Road Map		Component Class: Membrane									
Component attributes	Stack parameters	Measures	Importance	Impact potential by component technologies							
				PFSA Nafion type							
				Cast	Extruded	Composite	Grafted	PEEK	PAEK	PBI	Other
High crossover rate thickness	mL/min/cm²	4	1	1	1	3	3	3	3	3	3
High crossover rate thickness	TBD	4	1	1	1	3	3	3	3	3	3
High crossover rate thickness	TBD	3	1	1	1	3	3	3	3	3	3
Max operating temperature	°C	3	1	1	1	3	1	1	1	3	3
Price @ 2005 m2	\$/m²	5	1	1	1	3	3	3	3	3	3
Chemical resistance	Fuel/air/coolant loss	4	3	3	3	3	3	3	3	3	3
Conductivity at room temperature	Ohm	3	3	3	3	3	3	3	3	3	3
Conductivity at lower RH for a given Op T	Ohm	3	3	3	3	3	3	3	3	3	3
Membrane solubility	Swollen	4	3	3	3	3	3	3	3	3	3
Durability (mechanical/chemical)	Cyclic test (hours)	5	3	3	3	3	3	3	3	3	3
Electrical isolation	mV @ 1V	5	3	3	3	3	3	3	3	3	3
Dimensional stability	XYZ expansion	4	1	1	1	3	3	3	3	3	3
Crawl @ operating temp	% elongation	4	1	1	1	3	3	3	3	3	3
Manufacturability	TBD	3	1	1	1	3	3	3	3	3	3
Environmental friendliness	TBD	3	1	1	1	3	3	3	3	3	3
Recyclability	Up-take rate	4	3	3	3	3	3	3	3	3	3
Mechanical properties	TBD	3	3	3	3	3	3	3	3	3	3
Competitor's Position											
Relative Maturity											

## Stack Routemap

Internal Requirements: Published Technology Leadership Goals		2004	2005	2006	2007	2008	2009	2010
Cost (USD/KW net, 500 K units/year)		125	120	84	73	30		
Power Density (Watts net / L)		1200	1400	1800	2000	2200	2500	2800
Power Start (°C, seconds to 50% power)		<20°C/100s	<20°C/80s	<25°C/120s	<25°C/80s	<25°C/60s	<25°C/40s	<25°C/30s
Durability (DJR cycle hours)		2100	2100	2600	3200	3800	4400	5000
Stack and Unit Cell Routemap								
Performance								
MEA power density (W/cm²)		0.3XX	0.3XX	0.3XX	0.3XX	0.3XX	0.3XX	0.3XX
Platinum Specific Power Density (g/kW)		0.3XX	0.3XX	<0.3XX			<0.3XX	
Cell Design Attributes								
Total catalyst loading (mg/cm²)		0.3XX	0.3XX	0.3XX	0.3XX	0.3XX	0.3XX	0.3XX
Cell pitch (mm)		0.3XX	0.3XX	0.3XX	0.3XX	0.3XX	0.3XX	0.3XX
Stack Operational Robustness								
Stack cathode inlet RH (%)		100%	XX%	XX%	XX%	XX%	XX%	XX%
Peak Temperature Capability (deg C)		XX	XX	XX	XX	XX	XX	XX
Durability and Reliability								
Life time performance degradation (%)		<XX%		<XX%			X-XX%	
Component Routemaps								
Membrane		Standard PFSA	Chemically PFSA	Proton Goo	Proton Goo 2	Proton Goo 2	Proton Goo 2	Proton Goo 2
Catalyst		XXX/XXX/XXX	XXX/XXX/XXX	XXX/XXX/XXX	XXX/XXX/XXX	XXX/XXX/XXX	XXX/XXX/XXX	XXX/XXX/XXX
CCM		XXX	XXX	XXX	XXX	XXX	XXX	XXX
Wouldn't you like to read								
0.3XX-0.3XX								
XXX Cycles								
High surface blebs								
Improvement 4								
s=0.25								
Outmap								
XXX/XXX								
XXX/XXX								
3-45								
Magic seals								
1 Row without & recirc								
XXX/XXX								

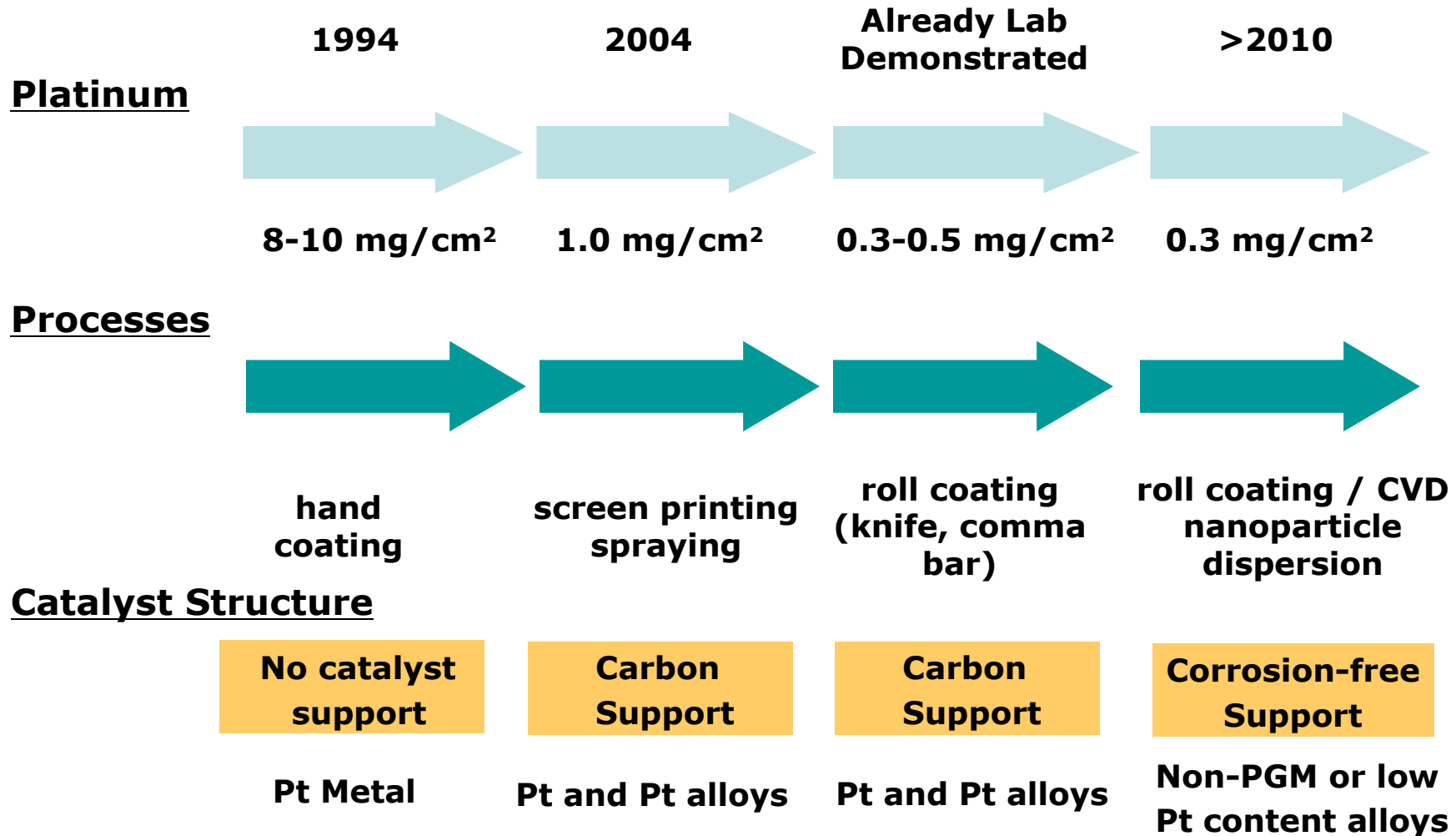
Internal technology planning process  
– detailed plans support the ability to  
meet the "Road Map" targets

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# Cost Reduction: Catalyst Technology Advancements

7

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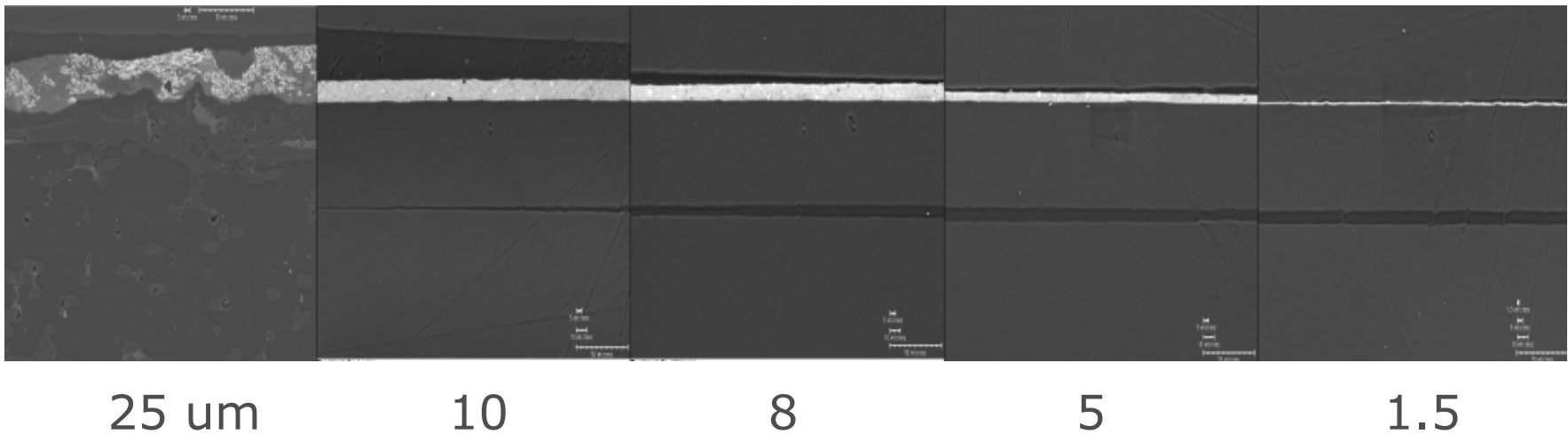
# Continuous Processing & Cost Reduction

8

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## Catalyst Reduction

- Tight control of catalyst loading and layer thickness



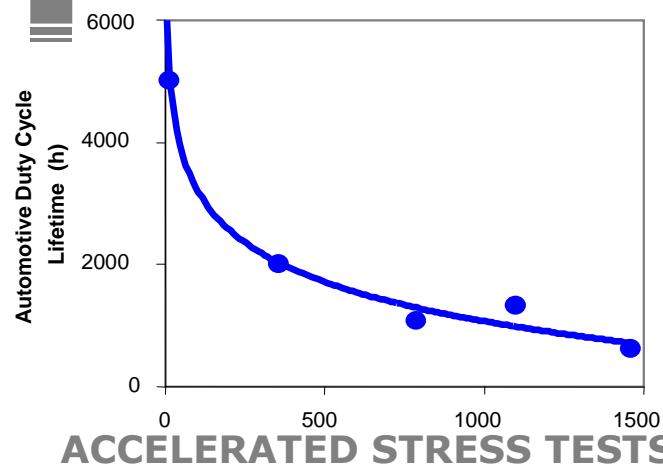
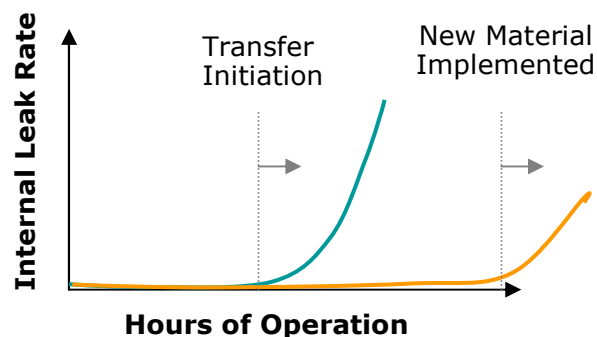
# Durability: Failure Mode Understanding and Mitigation

9

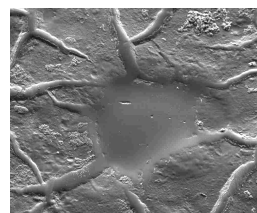
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## Internal Transfer Development – Peroxide Radical Attack on Perfluoroionomers

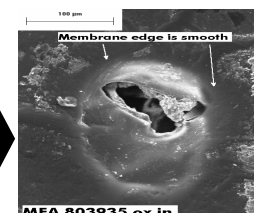
### OBSERVATION OF FAILURE MODE



### Thinning



### Rupture



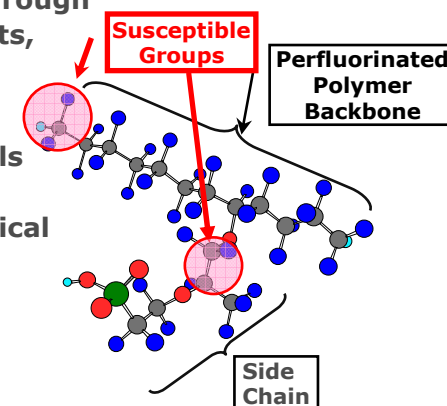
### FAILURE ANALYSIS

#### 1. Peroxide generation in fuel cell

#### 2. Peroxide radical production through reaction with Fenton's catalysts, such as iron ( $\text{Fe}^{2+}$ )

#### 3. Attack of membrane by radicals resulting in loss of material (thinning) and loss of mechanical strength

#### 4. Rupture of membrane due to mechanical stresses



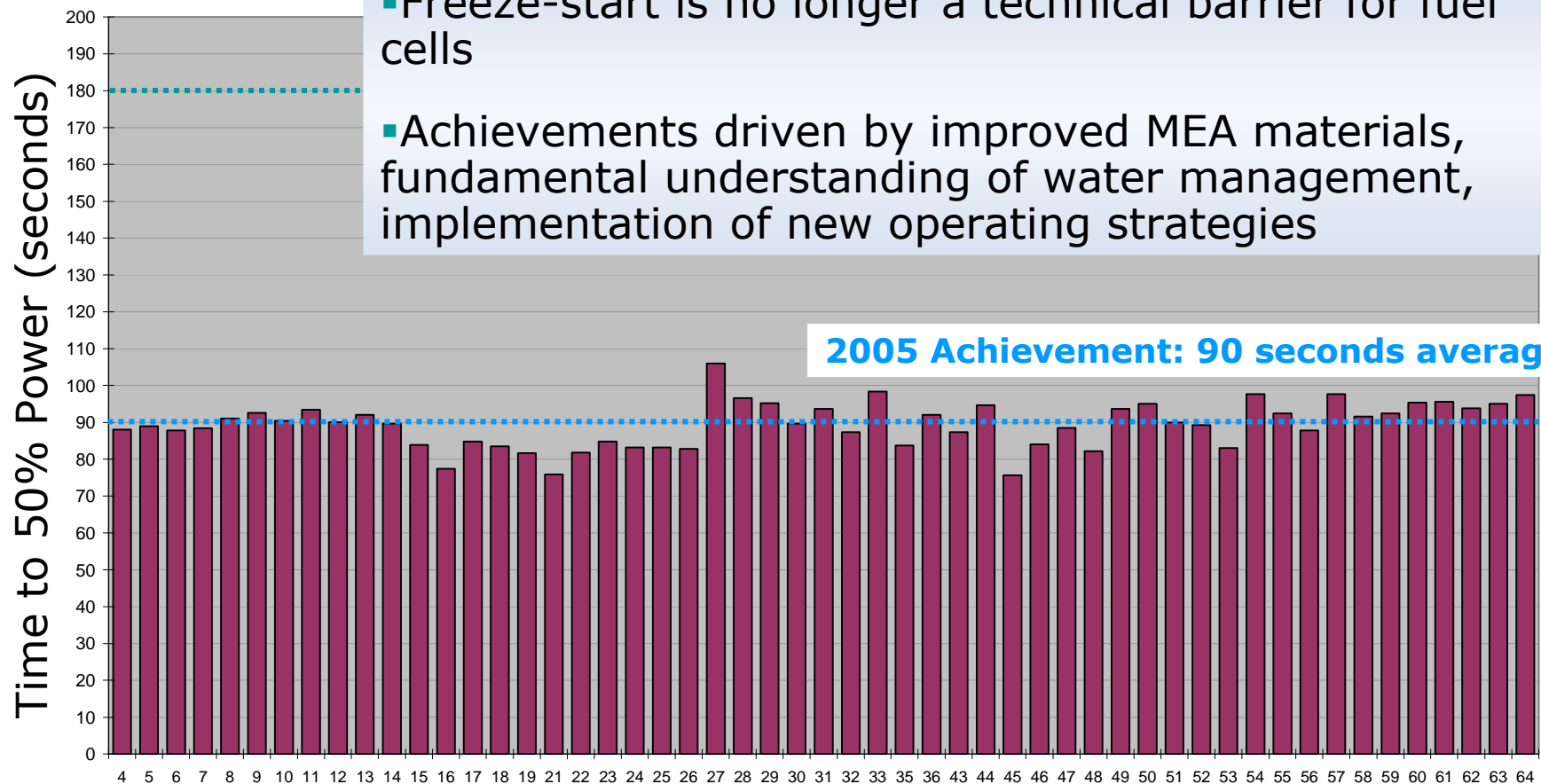
### FUNDAMENTAL UNDERSTANDING

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# 2005: Freeze Start from $-25^{\circ}\text{C}$ (Time to 50% Power)

10

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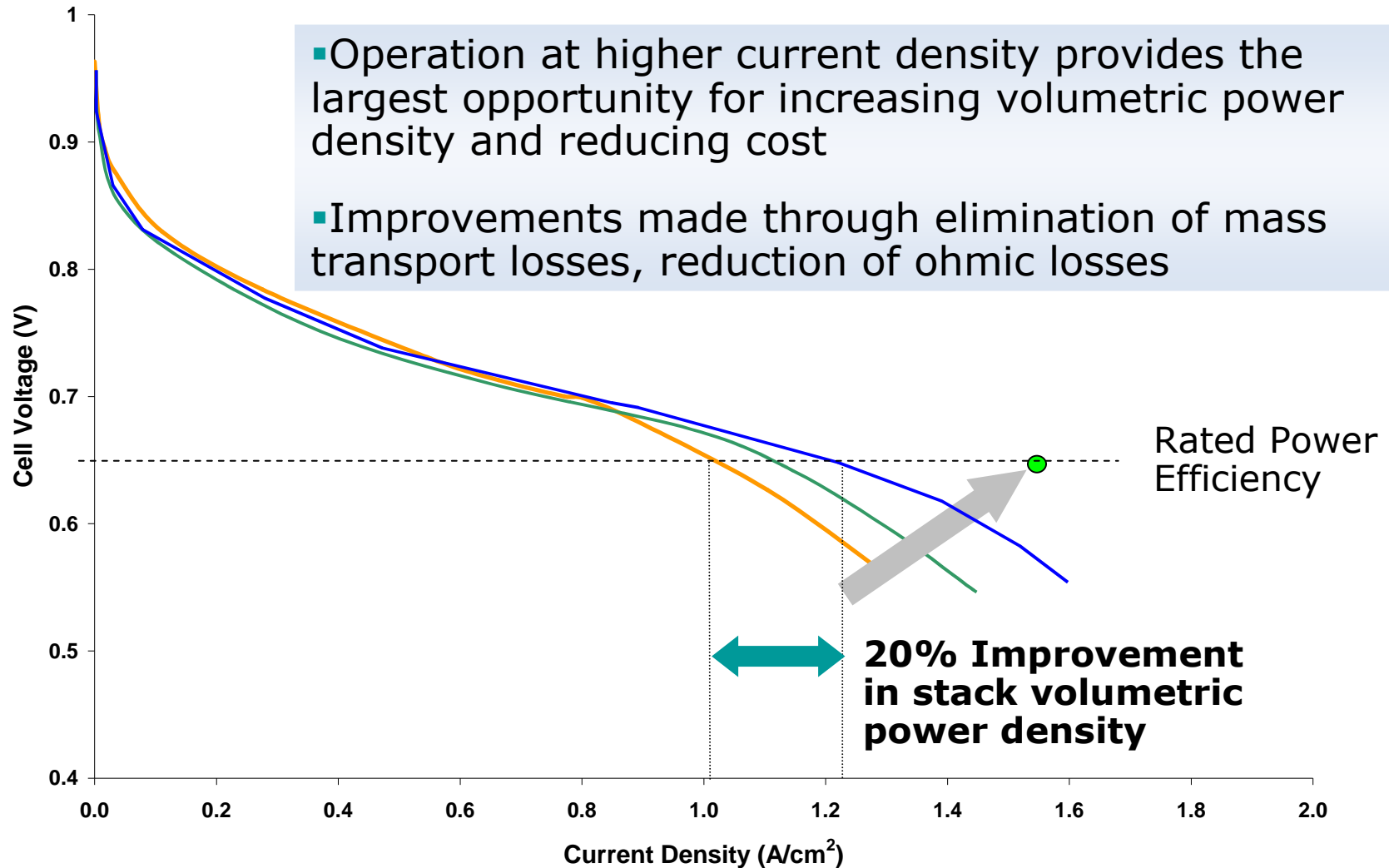


# Power Density

Polarization Curve Improvements

11

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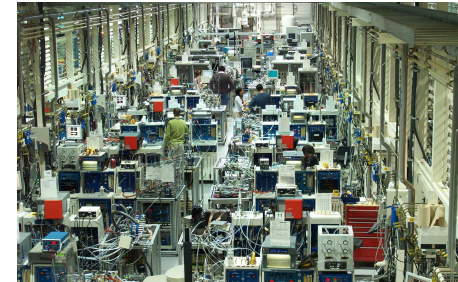
- Operation at higher current density provides the largest opportunity for increasing volumetric power density and reducing cost
- Improvements made through elimination of mass transport losses, reduction of ohmic losses

# Fuel Cell Test Facility

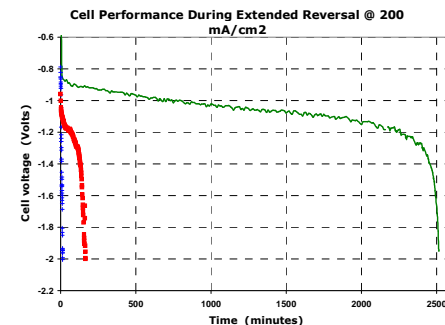
12

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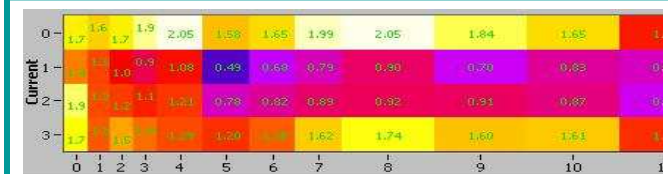
- World's largest test facility dedicated to fuel cell testing and research with more than 100 test stations
- 400,000 hours<sup>+</sup> of tests/year
- Units from < 100 W to 250 kW
- Test capability from -40°F to +140°F
- Three fully equipped failure analysis labs
- Integrated data collection and reporting
- Specialized Accelerated Stress Test (AST) equipment and protocols
- Advanced development testing tools



Test Lab



AST Results



Diagnostics –  
Current Mapping





# Real World Experience to Advance Technology



- 130+ vehicles
- 24 cities
- 5 million passengers
- real world data

Vehicles powered by Ballard fuel cells  
have logged 2 million miles



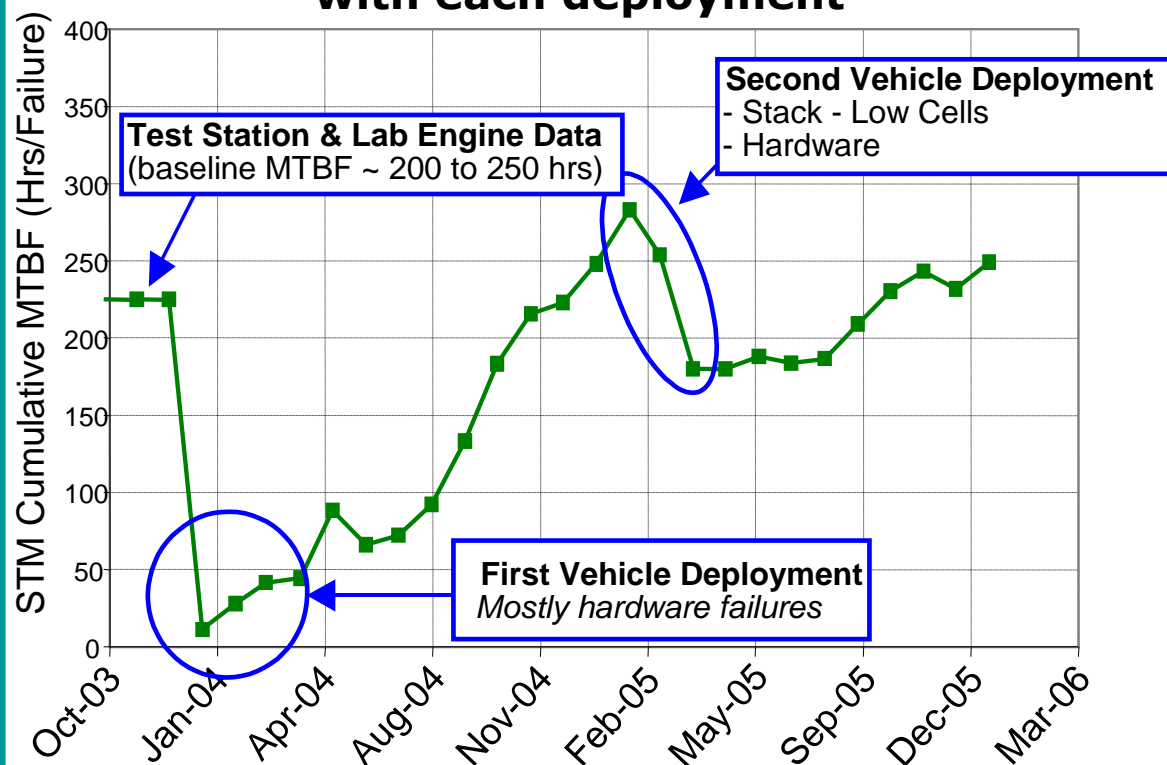
# Fuel Cell Fleets – Result in Reliability Growth and Technology Advancement

14

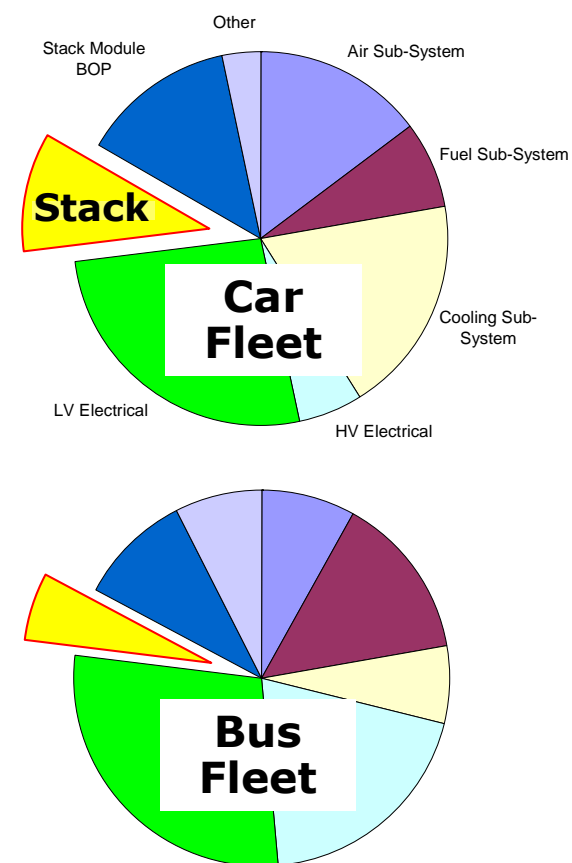
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## Fuel Cell Stack Module Reliability Growth

New failure modes & lessons learned with each deployment



## Majority of field failures are non-stack related



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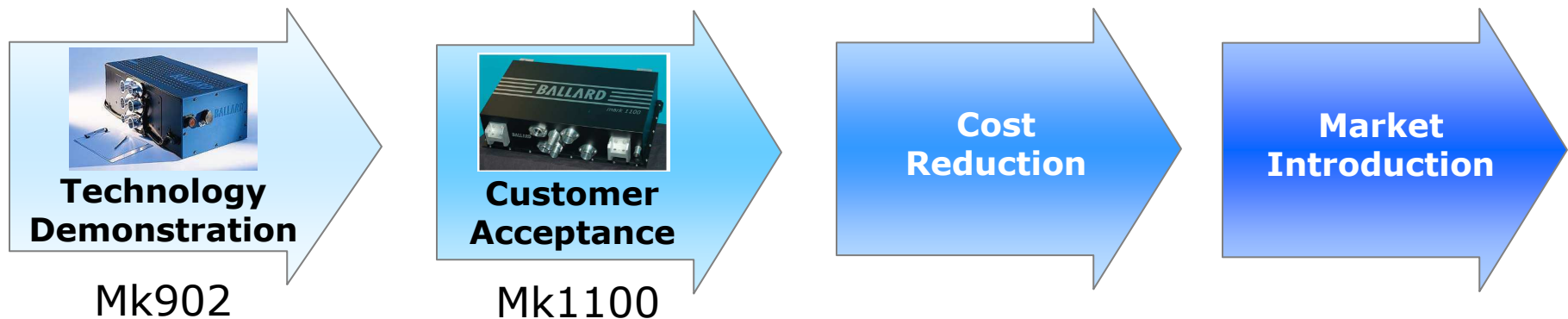


# Automotive Path to Commercialization

A slide titled "Automotive Path to Commercialization" with a blue background featuring a car's interior. At the bottom, there is a progress bar consisting of 18 squares. The first four squares are filled with different colors (dark blue, light blue, medium blue, and olive green), while the remaining 14 squares are empty white squares with blue borders.



Fleet	2005-2008	2009-2011	2012-2014	2015-2018
Technology	2001	2005	2008	2010



### Key attribute improvements of each generation

■ Durability	■ Power density	■ Cost reduction	■ Cost reduction
■ Power density	■ Durability	■ Power density	■ Reliability
■ Cost reduction	■ Robustness	■ Durability	
■ Freeze / thaw	■ Freeze start (-15°C)	■ Robustness	
	■ Design for manufacture	■ Freeze start (-25°C)	
		■ Design for manufacture	

- Cost reduction
- Reliability

# Manufacturing Capability

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## Fuel Cell Manufacturing Plant:

- Automotive certified supplier
- Installed capacity to meet CARB ZEV requirements of our customers through 2011
- Production quality prototypes, advanced process development
- Capacity will be added to manufacture volumes beyond 2012



 making fuel cells a commercial reality

# Summary

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- Fuel cells offer the best long-term alternative to the ICE
- Ballard has the R&D, product development, manufacturing, and financial strength to make fuel cells a commercial reality
- Ballard's published Technology "Road Map" is our public commitment to demonstrating commercially viable automotive fuel cell technology by 2010
- Ballard's partners have put 130 fuel cell vehicles on the road in 24 cities world-wide, significantly advancing the technology and proving the viability through real world usage
- Development of the next generation automotive fuel cell, the Mk1100, is on track

The ZEV mandate is an important driver for technology development and market adoption